Chapter 8

Constructing an Econiche

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8.0 Introduction

Ecological psychology is concerned with the relations that have evolved between organisms and their natural environments that support successful perceiving and acting. Yet, our species is currently unique in that it lives in an environment that is largely of its own construction, built in order to fine-tune or extend the job done by evolution. Most of the objects we grasp, surfaces we walk on, and shelters we inhabit are, for better or worse, artifacts. We are thus in the rather novel position of constructing our own econiche, or as the architect Lerup put it, "We design things and things design us." Yet, despite several decades of progress in ergonomics, there are still few general working principles for designing environments that fit the activities of human beings and anticipating the reciprocal effects on human activity.

Panero and Zelnick (1979) noted this when they described the assorted volumes of reference standards that are used by architects and designers: "Much of the available material is based almost exclusively on outdated trade practices or on the personal judgments of those preparing the standards. With few exceptions, most reference standards are simply not predicated on enough hard anthropometric data" (p. 12). Ecological psychology has something to contribute to such design problems, because ecological research is relevant to human action in the built environment as well as in the natural one.

8.1 Affordance Design

Several disciplines have emerged since the World War II that emphasize designing the built environment to a human scale. Ergonomics and human factors engineering have focused on the individual operator in the workplace, with the expressed purpose of "fitting the task to the man" (Grandjean, 1980; Shackel, 1976; Woodson, 1981). However, these fields are burdened with the often conflicting interests of increased productivity on the one hand and humanizing the workplace, including improved health and safety, on the other (Singleton, 1982). In the United States, much of this work was stimulated by the needs of the military and has tended to concentrate on rather specialized problems of the human-machine interface, such as cockpit design, process control, and instrumentation.

More recently, diverse research in environmental psychology and human ecology has examined larger scale interactions between environment and behavior (Canter & Lee, 1974; Ittelson, Proshansky, Rivlin, & Winkel, 1974; Stokols, 1977). This includes work on cognitive maps, personal space and crowding, the influence of behavior setting on social interaction, and preferences for environmental and architectural features. Also in the 1970s the field of environmental design emerged, emphasizing the human-scaled design of exterior and interior architectural spaces and, often, a participatory design process (Allsopp, 1974; Mikellides, 1980).

One of the contributions ecological psychology can make to this maze of problems is the concept of affordances. Gibson (1979) described an affordance as that which an environmental structure offers to a particular organism for activity, based on the relations between properties of the environment and that organism. Thus, a hard, flat, narrow surface may afford walking for me but not for a rhinoceros, and a horizontal surface at the height of my knees may afford sitting for me, but not for a small child. Now, it is the business of designers and architects to create places and objects such as these that afford walking, sitting, working, playing, and specific kinds of social interaction. In short, environmental design can be construed as the design of affordances.

As a nice example of this idea, Wise and Fey (1981) give their architecture students exercises in what they call Centaurian Design — designing things for use by four-legged, two-armed Centaurs. By radically altering the action capabilities of the organism, students are forced to confront the functional problems of designing new affordances.
to fit them. The entertaining results, which you may be able to imagine, include Centaurian umbrellas, elevators, and revolving doors.

The notion of an affordance offers both a unifying concept and a new perspective on problems of environmental design. It has the potential to unify previous work in the disparate domains of environmental psychology and ergonomics, because, in principle, an affordance analysis can be applied at a number of scales to the activities of an individual, group, or community. But the concept also provides a new perspective by emphasizing the material and informational bases for these activities in the fit between organism(s) and environment. Because most research on affordances has focused on the scale of individual actions, that is where I will concentrate. Some of these ideas have been recently articulated by Norman (1988) in his instructive and entertaining book, *The Psychology of Everyday Things*, even to the point of invoking the role of affordances in design. However, his interpretation of Gibson’s concept is less materially based and more subjectively determined that the one I provide here.

I begin by offering four tentative criteria for the successful design of affordances:

1. The design must fit the action capabilities of the user, or what Turvey and Shaw (1979) have called, the user’s *effectivities*. We all have our favorite examples of ill-fitting designs, such as the ungraspable doorknob (Figure 8.1) or the low doorway. The original F-111 military aircraft was plagued by a lever that was supposed to be pulled backward in order to close the wings for high-speed flight — consonant with the direction the wings moved, but quite contrary to the throttle, which had to be pushed forward in the opposite direction. Several crashes resulted before the lever was reversed. Occasionally things are intentionally designed so as to violate the user’s *effectivities*, as in the old trick of the castle staircase with an irregular riser, to trip up the marauding hoards.

   Successful affordance design requires a task-specific analysis of the organism-environment system that considers the relevant system variables and the biomechanics of the task. This is where ecological psychologists have made the most progress, and I’ll return to it later.

2. An affordance must be perceptually specified to the user, which implies that the designer understand the informational basis for action. This concerns not only lighting and noise levels, the focus of much ergonomics research, but also the arrangement of surfaces and their optical properties. Well-designed affordances should, in Koffka’s (1935) words, “name themselves” and actually lead the actions of the user.

   Violations of this principle are not uncommon. Gibson’s favorite example of an unspecified affordance was the modern plate glass window, an invisible obstacle that fells birds and humans alike. This is often remedied by unsightly markers on the glass at eye level, thereby compromising the effect of open space sought by the architect. Another problem is surfaces with texture that is too fine-grained or lacking altogether, yielding edges that are poorly defined both statically and by dynamic occlusion of texture. Examples include the steps in Saarinen’s Pan Am terminal at Kennedy Airport (see Figure 8.2; the black edging was a late addition and may only have made matters worse — on which side of the black strip is the edge?) and those in the carpeted lobbies of several conference hotels of my acquaintance. Due to the failure of underspecified affordances to “name themselves,” the architect Acking (1980) noted, “As the architecture gets worse, the number of signs increases.”

   This is not to suggest that all affordances are immediately perceptible without what James Gibson (1966) called the education of...
attention. Eleanor Gibson and her colleagues (Gibson et al., 1987) recently demonstrated that whereas young toddlers differentiate surfaces that afford walking and those that do not, crawlers of the same age do not. Thus, learning a new effectivity, walking, is accompanied by perceptual learning of the corresponding affordances. Such is the case with the discovery (or design) of new affordances by adults, as in the case of the “kneeling chair” with knee-pads and a seat but no back — learning the action of sitting in such a chair is accompanied by perceptual learning about its visual specification. Visual artists have played with violating the affordance properties of ordinary objects, producing such affordance puns as Surrealist Meet Oppenheim’s fur-covered cup and saucer, Lucas Samaras’ “Chair transformations” adorned with spikes and pins, Claes Oldenburg’s “Soft toilet,” and the left-handed coffee mug (with a hole below the lip if grasped by an unsuspecting right-hander).

3. Affordances must be designed to complement social patterns of use. This has been a major theme of research in environmental psychology. But it is important to note that such social patterns are not immutable — not only do we design things to fit us, but, reciprocally, things design us back (Reed, 1985). Discovery of the affordances of sharp-edged rocks, fire, and other implements had a profound impact on hominid evolution. Today the introduction of new technologies such as microcomputer workstations or virtual reality systems, however ergonomically sound their design, has far-reaching implications for the structure of work and social interaction.

4. The designer should strive to create objects that are not only functional, but also aesthetically satisfying. There has long been a tension in architecture between the fascination with formal style and the concern with functional space. In the case of modernist architecture, critics have argued that formal considerations tended to dominate, paradoxically violating the Bauhaus dictum, “Form follows function” (Allsopp, 1974; Brolin, 1976; Newman, 1980). Other designers suggest that there may exist a natural aesthetics of design that has a basis in function, much as the forms of the paradigm of beauty, Nature, have a basis in the structural and functional demands of physics and biology (Ghyka, 1946/1977; Hale, 1993; Humphrey, 1980). Meanwhile, the art of designing affordances is to work some ineffable unity between function and form.

8.2 Intrinsic Metrics

The method developed by ecological psychologists for the analysis of affordances is applicable to these criteria for design, particularly the first two listed earlier. Underlying the method is the principle of intrinsic metrics, which takes the action system as a natural standard for measuring the properties of the environment, in contrast to the imposition of an extrinsic metrics such as feet or meters. Such measurement is of necessity task-specific, because the relevant dimensions of the environment and the action system vary from task to task. When applied to environmental design, this notion leads directly to the principle of body-scaled or, more generally, action-scaled design. Although, as implied by the term body-scaled, I emphasize geometric dimensions of the actor and environment, the approach is readily generalized to other dynamic dimensions as implied by action-scaled. The phenomenological power of body scaling is brought home by a story my father tells about walking into a rest room recently to find that...
The notion of body-scaled design is, of course, not new. In fact, the first units of measurement were anatomical, such as the inch, the hand, the cubit, and the pace (Berriman, 1953). A number of systems have developed based on the proportions of the human figure, beginning with the Greeks’ use of the Golden Section. This is the ratio of the distance between the head and the navel to that between the navel and the ground in a standing man, approximately 1:1.618, which is repeated in the ratio of navel height to total height. However, this mystical value was applied not to the body-scaled design of interior space, but rather to the overall proportions of the Greek temple. Similar geometrical observations were made by Vitruvius (1960) in the 1st Century B.C., who pointed out that a man in two canonical postures defines a square and an inscribed circle with its center at the navel, later captured in Leonardo’s famous sketch of Vitruvian Man.

Le Corbusier (1954/1966), the supreme modernist, based his system of the Modulor on the Golden Section of a 6 ft. man with hand upraised. He extended two Fibonacci series down from these body ratios and decided that he had found “a harmonious measure to the human scale, universally applicable to architecture and mechanics,” upon which he based many subsequent projects. Although some appropriate body-scaled standards may have emerged from this scheme, such as ceilings at the height of the upraised hand, the Modulor was more a case of Le Corbusier imposing his own formal ideal on human space.

An empirical approach to body scaling developed with the study of anthropometry, which originated in anthropology and was soon applied to ergonomics (Damon, Stroudt, & McFarland, 1971; Roebuck, Kroemer, & Thomson, 1975). Bodies of anthropometric data are typically available to designers in the form of Dreyfuss figures (Figure 8.3), which present the 5th, 50th, and 95th percentile values for the lengths of various body segments in certain populations (Diffrient, Tilley, & Bardogji, 1974). Some of these anthropometric measurements have been translated into specific design recommendations for seating, work space, and so on, often without direct analysis of the tasks themselves.

There are three problems that I see in applying such anthropometric data to environmental design. First and foremost, anthropometric values are anatomical, not functional. Body dimensions are typically measured in standardized, static positions, whereas many environmental dimensions must be specific to the task and depend on the action performed. For example, the passage width of horizontal circulation spaces must take into account not only shoulder width, but also body sway, a comfortable safety margin, and cultural norms of “personal space.” Some research on functional or dynamic anthropometry attempt to address these questions, as in the classic studies of the reach envelope of the seated operator (Dempster, Gabel, & Felts, 1959; Hertzberg, 1960). But even here, the envelope depends on what action is performed with the hand — pushing a button, flipping a switch, or grasping a knob. As the ergonomist Kroemer (1982) argued, “More research is needed to establish better founded procedures to translate static body position data into functional design recommendations.”

The second problem is an extension of the first. Although design standards can be based on anatomical measurements, they typically provide no more than a range of recommended values. The notion of a comfort mode or optimal values scaled to the user is undefined, and no evaluation procedures for optimal action have been established.

The third problem is a practical one. Even when anthropometric data are available, they are seldom used by designers. In Ramsey and Sleeper’s (1970) Architectural Graphic Standards, the bible of the profession, the Dreyfuss figures appear on the first few pages — separate from the actual guidelines in the rest of the volume. Architects I have talked to admit they seldom refer to the standards anyway, typically relying on their own rules of thumb and constrained by the components that are available from manufacturers. In some cases these rules of thumb may reflect ecological folk wisdom derived from common constraints provided by the human body and the task demands (Drillis, 1963), but in other cases they can be misleading historical anomalies (Templer, 1992; Warren, 1984).

An affordance analysis could contribute to these problems by providing a dynamic, task-specific approach to human action. Using intrinsic measurements of the fit between the organism and the built environment, such an analysis attempts to identify critical points or limits at which a particular action breaks down and optimal points at which the action is most efficient, comfortable, or safe, depending on the task goals. Subsequently, the informational parameters specifying the affordance can be manipulated to determine what information is necessary for the perceptual guidance of action. Such an approach has been successfully applied by Hallford (1984) to the activity of grasping objects of varying size, by Carello, Grososky, Reichel, Solomon, and Turvey, (1989) to reaching objects at varying distances, and by Mark (1987; Mark & Vogele, 1987) to the problem of sitting height. As an
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8.3 An Affordance Analysis of Stair Climbing

Many of us have experienced the frustration of climbing "monument steps," standard equipment on many institutional buildings to provide an aggrandizing visual pedestal. The 5" to 6" risers on monument steps are too low to take them comfortably one at a time, but the 16" to 20" treads are too deep to take them two at a time. This seems to be a prime example of functional design sacrificed on the altar of aesthetics, but many architects also believe that a gentler slope is easier and safer to climb.

Why do monument steps feel so uncomfortable? How can we give the designer some guidance in creating environments that are better scaled to actors? For an ecological psychologist, these questions boil down to the problem of measuring an affordance, using methods of intrinsic measurement.

The relevant variables of this particular animal-environment system are complex, but by utilizing the techniques of dimensional analysis and similarity theory (Rosen, 1978; Schuring, 1977; Stahl, 1961, 1963) such a system of many variables can be reduced to a few dimensionless ratios, called $\pi$ numbers. As a simple example, if we measure riser height ($R$) with respect to the climber's leg length ($L$), we obtain a dimensionless, or unitless, ratio:

$$\pi = \frac{R}{L}$$

Thus, we are using a dimension of the organism as a natural standard for intrinsically measuring a reciprocal dimension of the environment. A specific value of this $\pi$ number expresses a particular fit between the climber and the stairway. Other $\pi$ numbers can also be derived using this method, but my experiments have focused on variations in riser height while holding the diagonal distance between stairs, corresponding to the climber's step length, constant.

Intuitively, as riser height is varied with respect to leg length, we would expect to find an optimal point ($\pi_0$) at which the energy expenditure required to climb through a given vertical distance is at a
minimum. Second, as riser height increases with respect to leg length, we will reach a critical point (\( \tau_{\text{max}} \)) at which the stair becomes impossible to climb bipedally, and the actor must shift to a quadrupedal hands-and-knees gait — a phase transition in behavior. This critical point can be estimated by a simple biomechanical model (\( L + L_1 - L_2 = R_{\text{max}} \)), which yields a value of \( \tau_{\text{max}} = .88 \) based on empirical measures of leg segments (see Warren, 1984, for derivation of this model). It follows from similarity theory that these optimal and critical points are constant over scale changes in the system, that is, critical riser height should be a constant proportion of leg length, regardless of the absolute size of the climber.

Beyond merely describing an affordance in this way, we must also determine whether it is perceptually specified. If the affordance is perceived, then its critical point should predict the perceptual category boundary between “climbable” and “unclimbable” stairs, and its optimal point should predict visual preferences for stairways. Ultimately, we wish to understand the optical information that specifies action-scaled affordances and how it is detected and used by the perception-action system.

Thus, an affordance such as the “climbability” of a stairway can be characterized by its critical and optimal points. It is important to note that these qualitative properties emerge from the dynamics of the ecosystem, that is, they are condensed out of variation in the relationship between the organism and its environment. Hence, functional perceptual categories and preferences can be shown to have a natural basis in ecosystem dynamics.

To test whether the perceptual category boundary could be predicted from the biomechanical model of critical riser height, I presented slides of stairs with risers varying from 20" to 40" to two groups of subjects; a short group and a tall group. The subjects were asked to categorize each as “climbable” or “unclimbable” and to give a confidence rating of their judgment. Categorization judgments are plotted as a function of absolute riser height \( R \) in Figure 8.4a, which shows a difference in critical riser height between the two groups; the confidence ratings also dropped to a minimum at these category boundaries. When the same data are replotted as a function of the \( \tau \) number \( R/L \), on what I will call intrinsic axes (Figure 8.4b), the curves are nearly congruent. This indicates that the critical point is a constant regardless of the size of the climber, as predicted from similarity theory. Further, the category boundary for both groups falls at \( \tau_{\text{max}} = .88 \), precisely as predicted by the biomechanical model. This result has been replicated and extended by Mark (1987) and Mark and Vogele (1987). Thus, it appears that the critical point of this affordance is accurately perceived.

The same should be true of the optimal point. Optimal riser height, defined in terms of energetic efficiency, was determined empirically by measuring oxygen consumption during climbing by short and tall climbers. Riser height varied from 5" to 10" with the diagonal distance between stairs held constant at 14" and step frequency constant at 50 steps/min. The results appear in Figure 8.5a, which shows a minimum energy expenditure per vertical meter of travel at riser heights of 7.7" for the short subjects and 9.5" for the tall subjects. These values are somewhat higher than common indoor risers of 6" to 7" and help to explain the trouble many people have with even lower monument steps. Far from making long flights of stairs easier to climb, low risers increase total energy expenditure by as much as 15%, and deep treads may make an efficient step length impossible as well. When the same data are

![Figure 8.4. Judgments of critical riser height: (a) Mean percentage of "climbable" judgments for each riser height, and (b) Intrinsic plot of "climbable" judgments as a function of the riser height to leg length ratio (R/L).](image-url)
replotted on intrinsic axes in Figure 8.5b, the curves become parallel with an optimal \( \pi_c = .26 \) for both groups. Thus, the optimal point also appears to be a constant over scale changes.

To see whether the optimal point predicts perceptual preferences, slides of pairs of stairways were presented to short and tall observers, who were asked to judge which stairway looked more comfortable to climb to the top. As shown in Figure 8.6, there is a group difference in preferred riser height, but the curves again collapse when plotted on intrinsic axes. The preferred riser falls at \( \pi = .25 \) for both groups, very close to the optimal point of .26.

Thus, it appears that critical and optimal points provide a useful characterization of an affordance, and also predict perceptual performance. When given functional tasks, subjects seem to perceive affordances, that is, they perceive the environment in functional body-scaled terms. This illustrates how affordance relationships can be objectively measured, and such information is essential to guide the successful design of affordances.

8.4 Walking Through Apertures

This type of analysis can be generalized to other affordances, and we subsequently applied it to the problem of walking through apertures or passageways of varying widths. What makes an aperture passable? The relevant intrinsic relation here is that between aperture width (A) and the widest body dimension, which in the case of typical men and women is shoulder width (S):

\[ \pi = A / S \] (8.2)
As this dimensionless ratio approaches 1, the actor must introduce shoulder rotation to pass through the aperture — another phase transition in behavior. However, the design of doorways, corridors, hatchways, and other horizontal circulation spaces cannot simply be based on this anatomical dimension, for the action of walking involves the additional factors of body sway and a comfortable safety margin. Thus, a task-specific affordance analysis is required to determine the critical point of minimum aperture width.

We evaluated critical aperture width empirically by videotaping small and large subjects walking through openings of different widths and measuring the amount of shoulder rotation. Figure 8.7a plots the angle of shoulder rotation as function of aperture width for each group. Critical aperture width was taken to be the point at which shoulder rotation increased above baseline levels of body sway, yielding values of 53 cm for the small group and 62 cm for the large group. When the data are replotted on intrinsic axes in Figure 8.7b, the curves become nearly congruent, with \( \pi_{\text{min}} = 1.3 \) for both groups. Thus, the critical point is again a constant over scale changes.

![Figure 8.7. Critical aperture width. Shoulder rotation as a function of (a) aperture width, and (b) the ratio of aperture width to shoulder width (A/S).](image)

When subjects viewed the apertures through a reduction screen at a distance of 5 m, their perceptual judgments of openings that are “passable” or “impassable” without turning their shoulders were similar. (The data appear in Figure 8.8.) The category boundary falls at \( \pi = 1.15 \), which indicates that subjects are slightly more conservative when actually walking through the aperture than when viewing it from 5 m away. Identical results were obtained when observers walked freely toward the aperture and stopped at a distance of 5 m, making more information about the layout of the room available from optical flow. Similarly, Carello et al. (1989) reported accurate judgments of the reachability of objects under static binocular viewing conditions. This raises the question of the visual information used to perceive affordances.

![Figure 8.8. Judgments of critical aperture width. Mean percentage of "impassable" judgments as a function of (a) aperture width, and (b) the A/S ratio.](image)
8.5 Intrinsic Information for Affordances

The last result suggests that there must be salient static information available to specify the body-scaled size of objects in the environment. A distinction can be drawn between metric and nonmetric information for size, distance, and shape: Nonmetric information would specify only the relative sizes of objects (e.g., on an ordinal or interval scale), whereas metric information requires the introduction of a scalar or standard to fix quantitative scale values (e.g., a ratio scale). Although there is growing evidence that the perception of shape from motion, shading, and texture is nonmetric (Koenderink & Van Doorn, 1991; Todd & Bressan, 1990; Todd & Reichel, 1989), the successful control of actions such as grasping, sitting, climbing, and walking through openings seems to require that some metric properties of affordances be perceived. Although it is often casually supposed that perceiving size and distance implies an absolute extrinsic metric (for example, distance perception tasks that ask for estimates in feet), it seems more likely that the perceptual system makes use of action-relevant or intrinsic metrics, for example, size and distance perceived in body-scaled units such as eye height or step length. In a sense, this turns a metric-size task into a relative size task in which one perceives the size of an object relative to one's own body.

A compelling case can be made that the perceived sizes of objects in a scene are scaled to the eye height of the observer. This was first discovered during the Renaissance by the practitioners of linear perspective, but was formalized only recently. A simple demonstration is to look in a dollhouse window — the tiny furniture and accessories appear life size because they are scaled appropriately to the observer’s eye height in the doll's room, that is, as ratios of the distance between the eye and the doll house floor. This effect was exploited in 17th Century Dutch peepboxes, parlor diversions that had an interior scene illusionistically painted on the inside and a peephole at the station point, creating the appearance of viewing a life-size room. The Dutch genre painter Pieter de Hoogh was obviously experimenting with eye height scaling when he painted an interior from two different station points (cf., e.g., “The linen cupboard” (1663) from the eye height of the adults, with “A mother beside a cradle” (c. 1659) from the eye height of the child). I'm told that architects often similarly scale their perspective drawings to the eyeheight of the client, so that structures appear properly scaled for the viewer.

There is a plethora of static and kinematic eye height information.

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Figure 8.9. Eye height information for object size: (a) Geometry of the eye height ratio for object A; (b) Explicit horizon: Eye level on an object is given by the height at which the visible horizon intersects the object; (c) Implicit horizon: Location of the horizon is given by the limit of optical texture convergence (vanishing point) and the limit of optical texture compression.
In recent experiments, when visual information is placed in conflict with other proprioceptive information, the results demonstrate that there is usable visual information for eye height in enclosed environments.

Related evidence shows that such eye height information is used not only to perceive eye level, but also to scale the sizes of objects in the visual scene. Stoper (1990) reported systematic effects of the pitchroom on judgments of object size, such that when the specified eye level was higher, objects resting on the floor appeared smaller — exactly what would be predicted by the eye height ratio. In our line of research on affordances, we showed that judgments of passable apertures were systematically affected by raising a false floor behind a peephole by 21.5 cm (Warren & Whang, 1987). This artificially reduced the specified eye height, making the aperture appear larger than it actually was and leading to a decrease of 4.5 cm in perceived critical aperture width.

The eye height hypothesis even offers a possible explanation of a famous size illusion often used to flog ecological accounts of perception. The Ames room is a trapezoidal room with a slanted floor that appears rectangular when viewed through a peephole at the appropriate station point. A friend standing in the far corner looks like a midget and expands into a giant upon walking to the near corner, an illusion that persists somewhat even if the observer is allowed to move (Gehringer & Engel, 1986). The standard explanation is based on perceptual expectancies: The observer selects a rectangular interpretation of the room from the family of all projectively equivalent rooms because of past experience in a carpentered environment. This distorts perceived distance and hence perceived size, following size-distance invariance. But why do we not rely instead on past experience with our friend, or on the radical violation of object constancy that occurs when she walks from one corner to the other?

In fact, the textures in the room are distorted so as to specify a rectangular layout of surfaces with a level floor (Runeson, 1988). The size "illusion" could thus be determined by the eye height ratio, independent of perceived distance: The far corner has a low floor, so that the friend's head is below eye level and she appears smaller than the observer; conversely, the near corner has a raised floor, so that the friend's head is above eye level and she appears larger. We see what is specified by body-scaled size information, contrary to any expectancies about our friend, and such size-scaling effects would apply to any object in the room. This is precisely what is reported by Stoper (1990) when he altered eye level in a different manner, by pitching the room.

This points to the fact that eye height information is only valid under certain conditions: when the ground surface is approximately level and when objects are resting on that surface. With sloping or uneven ground or objects suspended in midair, we would expect and often find systematic errors and illusions (e.g., Gibson, 1950, pp. 8.3).

\[
y/e = \beta/\gamma
\]

This simple relation holds if the height of the object is small relative to its distance from the observer; the more general equation is:

\[
y/e = (\tan \gamma + \tan \theta)/\tan \gamma
\]

where \( \theta \) is the visual angle of that portion of the object above eye level (which can be negative for small objects). This provides a scale not only for the height of the object, but for any object dimension in the frontal plane. Contrary to the generally accepted size-distance invariance hypothesis, this sort of information raises the possibility that perceived size does not depend on perceived distance, a speculation that has recently received empirical support (Haber & Levin, 1992). However, there are two obvious problems with the idea: The horizon is often not visible, and an observer's eye height may change from task to task.

Although the explicit horizon cannot be seen indoors, in a cityscape, or in a forest, there is still abundant information for eye level. As Gibson (1979) pointed out, the "implicit horizon" is specified by texture gradients on visible surfaces: Convergence and compression of ground texture can be extrapolated to a "vanishing limit" at the horizon (Figure 8.9c), and the convergence of wall texture specifies the horizon at its vanishing point. When the observer walks, the focus of the optical outflow pattern is at eye level on surfaces ahead. And, finally, eye level is perpendicular to the gravity vector, for which there is proprioceptive information from the feet, ankles, and vestibular system. In recent experiments, when visual information is placed in conflict with other proprioceptive information in a "pitchroom" apparatus which tips the visual scene fore and aft, even minimal optical structure can bias the perception of eye level by as much as 60% (Matin & Fox, 1989; Stoper & Cohen, 1989). Nemire and Ellis (1991) found that converging lines on the walls and floor of a pitchroom display (parallel to the depth axis) were sufficient to bias the perception of eye level, whereas lateral lines (orthogonal to the depth axis) had a much weaker influence. This is consistent with convergence information specifying an implicit horizon at eye level. These results demonstrate that there is usable visual information for eye height in enclosed environments.
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Sloping floors, multileveled terraces, and objects suspended in midair 
locations and orientations of surfaces 
really know about perceiving the layout of surfaces, designers should 
height information can be used to scale the sizes of objects and their 
judgments of maximum stair height shifted systematically upward, as a 
play 
Such an affordance analysis has three major advantages over traditional 
safety by providing sufficiently rich optical structure so that the 
vision that our own 
Thus, research from different traditions supports the idea that eye 
information can be used to scale the sizes of objects and their 
affordances. The implication for designers is to provide surfaces with 
sufficient optical texture and to locate objects on visible surfaces. 
Sloping floors, multileveled terraces, and objects suspended in midair 
may induce the kinds of body orientation and size illusions observed in 
the pitchroom and the Ames room. However, the eye height ratio was 
unaffected. However, after walking around briefly on the blocks, judgments rapidly shifted back to the 
original maximum height. This suggests that the visual system can 
rescale perceived size for changes in eye height with a bit of perceptual 
exploration. In effect, under some conditions we can see that our own 
eye height has changed. How this process works is a fascinating but 
unanswered question.

Thus, research from different traditions supports the idea that eye 
height information is actually used by the visual system. Stoper has tried to account for the “magnetic hill” illusion, in which objects appear to roll uphill, in just these terms.

A second problem arises because eye height changes as we stand, sit, step up, and so on, and yet we do not experience a corresponding expansion and contraction of our surroundings. Or do we? When Mark (1987) strapped 10-cm blocks to his observers’ feet, he found that judgments of maximum stair height shifted systematically upward, as a constant ratio of the new eye height. This occurred despite the fact that the maximum stair that could be climbed was not altered by wearing blocks, because thigh length was unaffected. However, after walking around briefly on the blocks, judgments rapidly shifted back to the original maximum height. This suggests that the visual system can rescale perceived size for changes in eye height with a bit of perceptual exploration. In effect, under some conditions we can see that our own eye height has changed. How this process works is a fascinating but unanswered question.

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dynamic properties such as object mass, rigidity and elasticity, surface friction and 
compliance, muscle strength and force production, joint stiffness, bone 
and joint stress, rates of energy expenditure, and so on. For example, 
the upper limit on climbable stairs in older populations may not be the 
geometric one due to leg length, but a dynamic one due to joint 
flexibility or muscle strength (Konczak, Meeuwsen, & Cress 1992; 
Warren, 1983). The present approach can be generalized to incorporate 
these variables in more complex π ratios, as is typically done in similarity theory. The more difficult challenge lies in determining the 
informational basis for perceiving such affordances, given that the 
information is not merely body-scaled, but action-scaled. There is 
potentially both static and dynamic information available to specify 
such dynamic properties across modalities, but we are only beginning to 
explore it (Bingham, Schmidt, & Rosenblum, 1989; Warren, Kim, & 
Husney, 1987).

To demonstrate that such a method really does have a contribution to 
making environmental design, Table 8.1 compares current architectural standards from Ramsey and Sleeper (1970) with the results 
of the ecological studies on stair height, seating height, passage width, 
and grasping size cited earlier. The so-called “ecological standards” are 
derived from π numbers by applying them to the appropriate anthropometric percentile value for the general population and, of 
course, are highly tentative. How these percentile values are selected is 
its own issue. The well-known fallacy of the “average man” (Daniels, 
1954; Panero & Zelnick, 1979) implies that one cannot best 
accommodate the majority of a population by designing for the 50th 
percentile; rather, different design problems require different criteria. In Table 8.1, the “ecological standard” for riser height is based on the 5th percentile to insure safe risers for the shorter end of the population, that for passage width is based on the 95th percentile to insure that the 
largest individuals can pass easily, and that for seating height is based on a range from the 5th to the 95th percentile, on the assumption that 
chairs should be adjusted to the individual user. The differences 
between architectural and ecological standards are more marked in

8.6 Conclusion

Such an affordance analysis has three major advantages over traditional 
anthropometry. First, it is dynamic and task-specific, analyzing actions 
as they are actually performed rather than relying on static anatomical measures. Second, the analysis yields π numbers, that is, body-scaled values for actors of any absolute size. The designer can then use the ratios to translate known anthropometric data into affordance values

for a specific population — men, women, children, the elderly, and so on. Finally, the method considers not just the physical dimensions of the environment, but also the perceptual basis for successfully guiding
action within it.

Although I have emphasized body-scaling and size, the affordances of the environment are clearly multidimensional, encompassing not only the geometric dimensions of objects and limbs, but dynamic properties such as object mass, rigidity and elasticity, surface friction and compliance, muscle strength and force production, joint stiffness, bone
and joint stress, rates of energy expenditure, and so on. For example, the upper limit on climbable stairs in older populations may not be the geometric one due to leg length, but a dynamic one due to joint flexibility or muscle strength (Konczak, Meeuwsen, & Cress 1992; Warren, 1983). The present approach can be generalized to incorporate
these variables in more complex π ratios, as is typically done in similarity theory. The more difficult challenge lies in determining the informational basis for perceiving such affordances, given that the information is not merely body-scaled, but action-scaled. There is potentially both static and dynamic information available to specify such dynamic properties across modalities, but we are only beginning to explore it (Bingham, Schmidt, & Rosenblum, 1989; Warren, Kim, & Husney, 1987).

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some cases than in others, but there is clearly room for improvement based on an affordance analysis.

In sum, this reconstrual of environmental design as the design of affordances could bear fruit for the architecture of public and private spaces, the design of furniture, equipment, and other implements, and for health and safety in the workplace. And the message for ecological psychologists is that when we study real problems of perception and action in real environments, the gap between basic and applied research is not so wide.

Table 8.1. Architectural and ecological standards for several affordances

| Architectural and Ecological Standards for Several Affordances |
|---|---|---|---|
| Riser height | Opt | 5-7 in | 7.5in | .26L |
| Seat height | Opt | 17.5 in | 14.5 - 17.5in | .47L |
| | Max | 2 ft 6 in | 2ft 3in - 2ft 8in | .87L |
| Passage width | Min | 21 in | 25in | 1.3S |
| Graspable object diameter | Max | - | 6in | .9G |

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Acknowledgments

This chapter was originally presented at the Third International Conference on Event Perception and Action, Uppsala, Sweden, June 1985. The present version remains largely faithful to the original, but adds a section on intrinsic information.

8.7 References

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